# BELLCOMM, INC.

SUBJECT: Superinsulated Cryogenic Storage for AAP - Case 610

DATE: June 24, 1968

FROM: P. L. Havenstein

## ABSTRACT

McDonnell Douglas Corporation has forwarded to OMSF a description of the "McDonnell Single Wall Cryogen Storage System" which has possible uses in AAP. This is a supercritical superinsulated single wall tank in comparison with the supercritical double wall Dewar tanks which have been used in Gemini and Apollo and are under development for the initial AAP missions. The McDonnell tank is shown to be less complex, lighter and cheaper but to require active ground cooling.

The memorandum concludes that the Dewars under development will do the initial AAP job with a minimum perturbation to spacecraft systems and to ground support equipment. For longer duration AAP flights which no longer require hydrogen but do require increasing quantities of oxygen and nitrogen there are significant weight advantages to using superinsulated single wall tanks and suitable prelaunch ground capabilities can be developed.

(NASA-CR-96031) SUPERINSULATED CRYOGENIC STORAGE FOR AAP (Bellcomm, Inc.) 7 p

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MEMORANDUM FOR FILE

McDonnell Douglas Corporation has recently forwarded to OMSF a description of the "McDonnell Single Wall Cryogen Storage System."(1) Attached to the correspondence were some photographs of a 39 inch cryogenic tank in fabrication, a "Proprietary" report, and a table (reproduced and attached to this memorandum as Table 1) which compares the salient characteristics of the Dewar tanks currently being developed for AAP with the McDonnell single wall tank. The McDonnell tank is shown to be lighter, cheaper,and simpler but to require active ground cooling. The general subject of superinsulated supercritical cryogenic storage systems (of which the McDonnell tank is a specific example) is well known and well reported so that the place of such systems in AAP can be evaluated without recourse to "Proprietary" information.

Gemini was the first manned program to use supercritical cryogenic storage of hydrogen and oxygen to supply reactants to fuel cells and breathing oxygen to the cabin atmosphere. The Gemini Dewar tanks carried about 24 pounds of hydrogen and 180 pounds of oxygen for the electrical power system. A Dewar tank or flask has an evacuated space between an inner and outer wall in which radiation heat exchange is controlled by barriers or surface coatings. Additional superinsulation was used outside the double-walled hydrogen tank of Gemini VII to further cut down heat leakage. Superinsulation is a system of radiation barriers which are effective only when operated in a vacuum such as the natural space environment.

Supercritical means tank operation at pressures above the critical point pressures (736 psia for oxygen and 187 psia for hydrogen) and permits the delivery of a single phase to the user systems. Subcritical operation requires either positive expulsion devices to maintain the liquid phase or special techniques to separate liquid from vapor prior to venting or delivery. On the whole, subcritical systems tend to be lighter but more complex than supercritical systems.(2) In this comparison both systems are supercritical.

The Apollo Program Service Module has a supercritical cryogenic storage system for fuel cell and cabin atmosphere uses. There are two hydrogen tanks with a total capacity of about 56 pounds and two oxygen tanks with a total capacity of about 640 pounds. The nominal operating pressures are 245 psia and 900 psia, respectively. Prior to launch the tanks are initially purged with dry nitrogen or helium gas and then filled with liquid oxygen or hydrogen at approximately atmospheric pressures. After a system chill-down period of up to 24 hours during which the liquids vaporize and are vented, the tanks are topped off and closed and the fill and vent connection removed. From this initial condition of an essentially saturated liquid at atmospheric pressure, the pressure begins to rise due to natural heat leak along a constant density line until it reaches the operating pressure as a supercooled liquid and can then begin to supply the fuel cells and Environmental Control System. The time from atmospheric pressure to operating pressure with natural heat leak only is called the standby time and is on the order of 24 hours. In practice the heaters and fans internal to the tanks are used to bring the system to operating pressure in less than two hours.[3] Up until launch the interior of the Service Module is purged with dry nitrogen to prevent the build up of frost on the outside of the Dewars.

AAP has under development larger tanks (41.5 in O.D., 39 in I.D.) to provide for extended duration operation of fuel cells and Environmental Control Systems. These tanks will weigh 300 pounds (without supports), operate between 850 and 950 psia, and have a standby time of 50 hours.[4] A Service Module installation will be three tanks with 225 pounds of usable hydrogen, three tanks with 3600 pounds of usable oxygen and one tank with 850 pounds of usable nitrogen (for a two-gas atmosphere). Because they will interface with existing equipment it's expected that they will be serviced and operated in a manner similar to Apollo.

As cryogenic quantities and mission duration increase there is a tendancy to increase the size of the Dewars. This is fundamentally because the surface to volume ratio and therefore the heat leak per pound of fluid decreases with size while for a given pressure and tank material the tank weight per pound of fluid remains fairly constant. This generalization is mitigated however, by a number of design factors. Currently about 15-20% of the total heat leak is contributed by the supports, plumbing, instrumentation and other accessories. As the area heat leak decreases these contributions become a limiting factor. The fraction of the heat leak which must be allocated to supports will depend on specific mission and system characteristics. Another design factor is the weight of the outer shell of the Dewar. While the inner shell is designed by tensile loads, the outer shell is designed by the compressive loads of the atmosphere and tends to fail in buckling. As tank size increases this shell must be stiffened with attendant weight increase or additionally supported from the inner shell with attendant increase in thermal leak.

The concept of superinsulation makes use of the natural vacuum of space to replace the vacuum jacket of the Dewar. A single wall tank is surrounded by radiation shields and in a vacuum the heat transfer is approximately inversely proportional to the number of shields. A promising example of a radiation shield is crinkled Mylar, aluminized on one side, with 30-40 layers occupying about one half inch in thickness.(5) This type of insulation can sharply reduce heat leak for orbital flight with very little weight penalty. The principle orbital problems are tunneling and gas entrapment. Tunneling occurs when the spacing between layers is reduced to a fraction of the wavelength of the peak of the black body emission curve and is usually created by structural or other pressures external to the insulation.(6) Gasses trapped between the layers by insufficient local venting will increase heat transfer by molecular conduction. With such an efficient area insulation the heat leaks of supports, plumbing, instrumentation and accessories becomes still more important and may amount to half of the total. The McDonnell approach is to support the tank on low conductivity fiberglass tension ties wrapped with superinsulation. With most bonding resins the tensile, compressive, and flexural strength of fiberglass all increase at cryogenic temperatures.(5) The effectiveness of this approach has probably been demonstrated by McDonnell's preliminary tests which indicated an orbital heat leak of less than 9 Btu/hr for a 39 inch tank.

The superinsulated tank can be lighter and better insulated than the Dewar for orbital operations, but it does so at the expense of prelaunch performance. It is probably appropriate for really long duration flight requiring large quantities of atmospheric gasses to emphasize orbital performance over ground performance because tank weight becomes a large fraction of the payload. The AAP-3 empty tank installation, for instance, weighs about 2000 pounds. Certain minimum prelaunch performance, however, is still required. McDonnell has added three things: a substrate of foamed polyurethane, a cooling coil exterior to the tank, and a gas-purged polyethylene bag outside the superinsulation. With these steps the prelaunch heat leak for the 39 inch oxygen tank is still estimated to be 500 Btu/hr and the standby time without cooling is 18 hours; the standby time of a hydrogen tank is only 3.2 hours. With cooling, standby times can be extended indefinitely. The exterior of the tank and the superinsulation is usually purged with dry nitrogen, for oxygen and nitrogen tanks, and with dry helium, for hydrogen tanks. This prevents formation of frost and atmospheric cryo-pumping and the attendant increases in weight and heat leak.

In summary, it is apparent that the 41.5 in Dewar tanks under development for the initial AAP flights will do the job and will do it with a minimum perturbation to other spacecraft systems or to ground support equipment and procedures. The substitutions of superinsulated tanks would require additional spacecraft modifications and a major alteration of ground support equipment for testing and prelaunch activities. This is particularly true of the hydrogen tank with its requirement for cooling with helium or slush hydrogen.

For longer duration AAP flights, however, superinsulated tanks will definitely be preferred. First, fuel cells will give way to solar cells as the primary power source and as a consequence hydrogen storage will no longer be required. Second, as duration increases the need for the more effective potential orbital performance of superinsulated tanks increases. Finally, as atmospheric gas quantities increase and optimum tank sizes increase the weight advantage of single wall will become increasingly significant. It is apparent from the McDonnell report and other studies that suitable prelaunch ground capabilities can be developed.

1021-PLH-dcs

P. L. Havenstein

Attachment

## References

(1) McDonnell Douglas letter to Dr. G. E. Mueller, JFY-154, 20 May 1968, Subject: McDonnell Single Wall Cryogen System

(2) Space-Cabin Atmospheres, Part IV, NASA SP-118, 1967

(3) CSM Master End Item Specification, Block II, SID 64-1345B, 1 January 1968

(4) AAP Standard CSM Configuration, NAA, 12 April 1968

(5) Advances in Cryogenic Engineering, K. D. Timmerhaus, Editor, Plenum Press, Volume II, P 49-55

(6) Applied Cryogenic Engineering, R. W. Wance and W. M. Duke, 1962, Wiley

Enclosure (1)
JFY-154

| | DEWAR* | MCDONNELL SINGLE WALL |
|---|---|---|
| Unit Cost (first 10) | $130,000 | $75,000 |
| Empty Weight | 340# total | 283# total |
| Performance | | |
| Ground | .3% Boiloff in 24 hrs. | Zero boiloff as long as ground cooling is used. |
| Orbital | Approximately 10 BTU/hr. predicted. | Less than 10 BTU/Hr. heat leak measured. |
| Active Ground Cooling | Not Required | Required |
| Orbital Regeneration Cooling | Inner shell supports and Vapor Shields require cooling | Not required - if used, will increase orbital thermal performance |
| System Complexity and Related Reliability Penalty | Higher | Low |

* Estimated Values

TABLE 1

**BELLCOMM, INC.**

Subject: Superinsulated Cryogenic Storage for AAP - Case 610

From: P. L. Havenstein

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